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No. 393

STALL-PROOF AIRPLANES

By G. Lachmann

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By G. Lachmann

Economy and safety are closely related viewpoints for air traffic, since an increasing confidence in the reliability of airplanes will find expression in their increased use by the public. Just during the past year we have had to record an alarming number of stalls (not only of sport planes but also of large commercial airplanes), which are not calculated to increase the confidence of the public in the safety of flight, notwithstanding all the statistical proofs of the relatively equal safety (or lack of safety) of railway and air traffic.

Generally speaking, the blame for a stall is ascribed in the newspaper reports to the failure of the engine. It is reasonable to expect a diminution of such accidents through the increased use of multi-engined airplanes. Therein, however, lies a certain acquiescence, the admission of an inherent danger in an airplane from the failure of the source of power. The use of additional engines avoids this danger, but does not entirely remove the evil.

My lecture, therefore, has to do with the following questions. Is the danger of stalling necessarily inherent in the airplane in its present form and structure, or can it be diminished or elimi-

* "Absturzsichere Flugzeuge," a lecture delivered before the W.G.L. at Munich, Germany, in September, 1925. From Yearbook of the W.G.L. for 1925 ("Berichte und Abhandlungen der W.G.L." May, 1926, pp. 86-90.)

nated by suitable means? Do we possess such means or devices and how must they operate? In this connection I will devote special attention to the exhibition of stall-proof airplanes by Fokker under the auspices of the English Air Ministry, which took place in Croydon last April.

Stalling, as Regarded from the Standpoint of Flying

Contrary to most, not to say all, other kinds of motion, flying begins to be dangerous when the speed decreases. Accelerations, which occur in steep gliding flight or in nose dives, are generally less dangerous than reductions in speed, as, for example, in flattening out of a dive or in so-called stalled flight.

How does a typical airplane stall occur? According to my own very clear remembrance of a stall eight years ago, the process is somewhat as follows. Shortly after the airplane takes off, the engine begins to slow down and then to misfire. The pilot sees the edge of the aviation field immediately in front of him. At the best, it is the question of a bad landing place, vegetable garden or the like. At the worst, there are houses, barns, etc. In most cases, and in spite of all instructions and warnings to the contrary, the pilot usually makes the famous (or, rather, infamous) "distress" curve, in order to get back over the field. A better way, in such cases, is to fly straight ahead and take one's chances with pancaking or sideslipping into a garden. In the curve, he feels the pressure leaving the controls, and the

airplane begins to sink and sideslip. If he attempts to right the airplane out of its tilted position, he notices that it does not respond to the ailerons and, instead of coming out of the curve, begins to turn more strongly about the inner wing. Finally, the airplane goes over the wing on to its nose and begins to spin or plunges vertically down. The altitude at the disposal of the pilot is seldom sufficient to enable the airplane to flatten out and in most instances the catastrophe is sealed by striking the ground.

Crashes from high altitudes are relatively rare. They are generally due to the pilot's losing his head or to his lack of experience with the spin (a fault in his training), inability to bring the airplane out of the spin through the operation of the controls (a structural defect through unfavorable distribution of the weight, which is typical for most low-wing monoplanes), too small tail surfaces, or failure of some part in the air, from faulty construction due to defects in the materials, errors in assembling or in computation, faulty inspection, intervention of the elements. All of the causes, with the exception of the last, are avoidable and not inherent in the present form of the airplane. Considerable progress has therefore been made when it is found possible to maintain the efficacy of the steering controls even in greatly retarded flight, so as to avoid undesired motions of the airplane.

Aerodynamic Relations in Flight at Large Angles of Attack

Notwithstanding the danger of repeating much that is partially known to you, I consider it expedient to explain briefly the phenomena of flow about a wing at large angles of attack. It is known that the lift of a wing increases approximately as the angle of attack only up to a certain point, the lift curve attaining its maximum at $15-18^{\circ}$ (Fig. 1). Any further increase in the angle of attack causes a separation of the flow from the top of the wing. At this point the lift decreases and the slope of the lift curve $\frac{d c_L}{d \alpha}$ becomes negative. The angle of attack at which this occurs is called the critical angle of attack and the point itself is termed the burble point or stalling point. The separation or detachment of the air flow begins in the middle of the wing span, where the aerodynamic angle of attack is the greatest, due to the distribution of the lift not being exactly elliptical, and gradually spreads to the wing tips. There is a limited angle-of-attack range, within which the flow at the wing tips is still "healthy," after it has already separated in the middle.

Figs. 2-3, which are photographs of some of my earlier experiments in the Göttingen laboratory, very clearly illustrate this phenomenon. The wing section or profile, from which the flow is detached, was in the middle of the wing, while the other profile was in the "healthy" or normal flow at the wing tip. The geometrical angle of attack was the same in both cases. It

is noteworthy that the travel of the center of pressure, after the separation, is in the direction of stability, that is, any further increase of the angle of attack develops a nose-heavy moment.

These flow phenomena are closely connected with a certain form of motion termed the "autorotation" of the wing, which can either be produced artificially in a wind tunnel or observed in a spin in actual flight.

We will imagine a wing so mounted that it can rotate about an axis which is parallel to the wind direction (Fig. 4). Any impulse which brings the wing into the direction of the dotted line, produces on the left a downward and on the right an upward flow component. The resultant flow vector is thereby inclined downward at the left wing tip, i.e., the angle of attack is diminished, while at the right wing tip the angle of attack is correspondingly increased. So long as we are in the region below the critical angle of attack, a stabilizing or restoring moment is developed, which tends to return the wing to its original position. If the critical angle of attack is exceeded, a moment is developed in the same direction as the impulse which produces the abovementioned autorotation.

The connection between the angle of attack and the peripheral velocity of the autorotation is very clearly shown by the experimental results represented in Fig. 5, which were obtained in the Gottingen laboratory and which were very kindly placed at my

disposal. Fig. 6 shows the position of the biplane model, with an axis of rotation passing through its center of gravity. Fig. 5 shows that, only after the critical angle of attack is exceeded, a rotation sets in, whose peripheral velocity increases with increasing angle of attack.

The connection between autorotation and angle of attack is explained by the fact that spinning and related motions (rolling) are possible only in the region above the critical angle of attack of the wing. Spinning and autorotation are impossible, however, even in stalled flight, when a warping moment is successfully exerted against the direction of the autorotation.

According to Hopf, another possibility consists in balancing the inertia moments of an airplane about its lateral axis. Hereby disappears the tail-heavy gyroscopic moment otherwise developed in spinning and which balances the nose-heavy moment developed at large angles of attack.

The equilibrium conditions for stalled flight have been theoretically elucidated by the fundamental researches of Hopf in Germany and Bairstow in England. Unfortunately, we have hitherto neglected in Germany to investigate experimentally, hand in hand with theoretical research, these phenomena which are so extremely important for the safety of airplanes. In Anglo-Saxon countries, especially in England, the problem of control at low speed has long been one of the principal subjects of practical research.

Action of Elevator in Region above Critical Angle of Attack

For the elevator, the theoretical investigation, in agreement with practical experience, gave the following results. In stalled flight the elevator changes the angle of attack in the normal direction, i.e., pulling the control stick increases, and pushing decreases it. Increasing the angle of attack, however, decreases the speed and increases the inclination of the flight path, thus producing the opposite to the desired effect.

As regards the rudder, it may be said that it loses its effectiveness, partly through the decrease in the dynamic pressure and partly through the increase of the moments about the vertical axis of the airplane. At large angles of attack, the rudder is also often shielded by the fuselage and is affected by the boundary layers of air released from the wings and fuselage.

The ailerons have a decisive effect on the stability in stalled flight, but their action can not be explained by purely analytical reasoning. Previous researches of a theoretical nature therefore shed very little light on this subject. The following explanation of the action of the ailerons in stalled flight is based on a series of wind-tunnel experiments made in England.

Every aileron deflection causes a rotation about two axes perpendicular to each other, a rolling motion about the longitudinal axis and a yawing motion about the vertical axis of the airplane. The rolling moment is proportional to the respective

lift increase or decrease on the side of the lowered or raised aileron. The effect of the lowered aileron, however, is annulled or reversed, as soon as $\frac{d \text{ CL}}{d \alpha}$ becomes negative, that is, when the region above the critical angle of attack is reached. Hence the rolling moment is greatly diminished in stalled flight and, under certain conditions, acts in the opposite direction of rotation.

The rolling moment, developed by every deflection of the ailerons, simultaneously develops a yawing moment, which is always opposed to the desired direction of turning. This fact was established by the Wright Brothers on their first airplanes and led to the well-known coupling of the aileron and rudder controls.

The cause of this moment, at small angles, is chiefly the increase in the induced drag on the raised wing side. At large angles of attack and above the critical angle, this moment is due to the disproportionately great increase in the profile drag caused by the development of the boundary layer and the detachment of the flow on the depressed aileron. According to wind-tunnel tests, which were confirmed by practical experiments by Melville Jones in England, the opposing moment of yaw can, in stalled flight, assume high values and far overbalance the effect of ordinary rudders. A partial remedy has been supplied by De-Havilland's differential steering controls and by the Bristol "Frise" aileron-balancing device.

Means for Retaining Steering Control in Stalled Flight

When we succeed in maintaining the effect of the steering controls, especially of the aileron controls, in stalled flight, the latter will lose much of its danger and the cause of 90% of all airplane crashes will be largely eliminated.

The method successfully employed by Fokker on the F.VII depends simply on a skillful utilization of the aerodynamic properties of normal wings without additive devices. The wing section or profile is so shaped that the lift curve shows a flat descent in the region above the critical angle. Thereby the disastrous effect of stalled flight and the inception of auto-rotation is largely avoided. Aerodynamic engineers know how such profiles must be shaped (see also Fig. 1).

The effect of the ailerons at large angles of attack, or large inclinations of the airplane axis, is increased by the decrease in the angle of attack toward the wing tips. The wing tips are therefore made narrower than the middle of the wing. This is due to the fact that, because of the trapezoidal shape of the wing, the rolling moment of the ailerons decreases less at large angles of attack than with rectangular wings. (In this connection, see N.A.C.A. Technical Report No. 169, 1923, "The Effect of Airfoil Thickness and Plan Form on Lateral Control," by H. I. Hoot.)

The essential point of the problem, the retention of lateral control in the stalled condition, is this: the disastrous effect of stalled flights and the inception of auto-rotation is largely avoided. Aerodynamic engineers must now

stability, can not, however, be decisively affected by this means alone. In fact, on the Fokker F VII airplanes, stalled flight is simply developed and every curve is avoided. A considerable improvement in this direction is effected by using a device, which brings the slot effect to the aid of the aileron effect. An airplane of this kind was exhibited at Croydon and surprised the skeptics by its remarkable performances and especially, by the fact that Bulman described curves in completely stalled flight, without sideslipping and going into a spin in the well-known manner.

I will endeavor to explain the principle of this device, without claiming it to be the only solution. It has, however, given the best results yet obtained and its application offers no structural difficulties.

The peculiarity of the slot effect consists in the fact that the region below the critical angle of attack is nearly doubled, whereby the profile drag is simultaneously decreased by delaying the separation. A simple auxiliary airfoil (a bent sheet of duralumin) is hinged to the leading edge of the wing and connected with the aileron in such a way that, when the latter is depressed, a slot is formed in front, while the auxiliary airfoil is not actuated when the aileron is raised.

The air flow thus produced past the ailerons is diagrammatically illustrated by Fig. 7. When the aileron is depressed, a normal flow is developed with the aid of the slot, i.e., increasing lift with small drag, while, on the other side, the flow re-

mains separated, with small lift and large drag. In this way a very powerful rolling moment and a very small or negative yawing moment is developed, that is, a moment turning in the same direction as the rolling moment. The device works on the principle of utilizing the separation itself for the control.

A similar principle is followed in the simple slotted-wing aileron, in which there is a wedge-shaped slot between the wing and the aileron. Such ailerons have been very successfully used in Germany on the Heinkel airplanes. Of course the effect of the slotted-wing ailerons can be considerably increased by the above-mentioned combination with the auxiliary wing.

This device has been the subject of a long series of wind-tunnel tests in England, which were performed in the National Physics Laboratory,* under the direction of the Aeronautical Research Committee (British).

The experiments were all performed on a thin wing (R.A.F:15 or Avro profile). The aileron had no slot, but was balanced in many of the experiments after the manner of the Bristol ailerons. The dimensions of the model were: chord, 6.42 inches; span, 35.24 inches; aspect ratio, 5.55. The index value was accordingly 3000 at a velocity of 59.7 feet per second. I recalculated the English coefficients according to the German standard and obtained

$$c_{mr} = \frac{M_r}{b^2 t q} = \frac{M_r}{F b q} ,$$

* Reports and Memoranda No. 916 (1925), "Slot Control on an Avro with Standard and Balanced Ailerons," by F. B. Bradfield.

for the rolling moment and

$$c_{mg} = \frac{M_g}{b^2 t q} = \frac{M_g}{F b q} .$$

for the yawing moment.

Fig. 8 shows the rolling moment as a function of the angle of attack at $+10^\circ$ aileron deflection. The curves for the standard ailerons alone and for ailerons in combination with an auxiliary airfoil are both plotted in this figure. For the latter, the solid lines indicate the courses of the moments at the best width of slot, while the dashed curves are for slot widths of 1.65 mm (0.065 in.) and 3.3 mm (0.13 in.), respectively. The diagram clearly shows how the slot affects the moment below an angle of attack of 10° . At 35° the coefficient of the combination is about six times as large as for standard ailerons alone. Fig. 9 gives the same relations for aileron deflections of $\pm 20^\circ$.

Fig. 10, which was derived from one of the last experiments, gives the yawing moment as a function of the rolling moment for various slot widths (s) and angles of attack. This diagram shows very clearly how the yawing moment appreciably decreases with increasing width of slot and even attains negative values under some conditions. On the basis of this experimental result, it would therefore be possible to describe a curve with the correct obliquity, by the action of the ailerons alone, without using the rudder. In fact, this was done by Bulman at the Croydon exhibition.

Postscript on Going to Press

It was planned to exhibit the device, at the close of the session, on a Udet "Flamingo," but unfortunately the airplane was not finished in time. It may therefore be of interest to quote from the report of the tests made in England on an Avro airplane:*

Full Scale Flying Experience

"The model results seem to be completely substantiated by the performance of the full scale airplane. The Avro can be glided stalled and with the feet removed from the rudder bar, rocked from side to side by the ailerons without any appreciable yawing. If when gliding stalled, the left rudder, say, is applied, a turn to the left develops, and the airplane immediately drops the left wing; rapid application of right stick quickly raises this wing again to the horizontal, and centralization of the ailerons and rudder results in a return to the steady, straight stalled glide. If the ailerons are only applied very slowly, the left wing can not be completely lifted, and the airplane does a slow, flat, left-hand turn, with about 15° to 20° bank. When, gliding stalled as before, full left rudder and right stick are applied simultaneously, the airplane first banks to the right; but, as the rudder comes into action, it slowly swings over to the left, and takes up the same flat spiral mentioned above. A proper

* Aeronautical Research Committee (British), Reports and Memoranda No. 968, March, 1925.

spin can only be induced by using full rudder and full aileron in the same sense, and the airplane can be brought on to an even keel again by rapid reversal of the ailerons, even though the rudder is kept full on and the stick hard back; centralization of the rudder and ailerons at this moment again results in a return to the straight stalled glide. With full engine the rudder is, of course, relatively more powerful, and more time is required to pull up the dropped wing against the rudder; it can, however, eventually be pulled right over into a sideslip in the contrary direction after about 180° turn.

Conclusion

"There is no doubt that this form of lateral control has greatly increased the safety of flight in the region of the stall. It is quite likely that it could with advantage be applied to fighting airplanes, as the ability to start a turn rapidly and to maintain lateral control when stalled with full engine, on a turn of minimum radius, is of very great importance.

"Both model and full scale experiments were made to see whether the drag of the airplane had been increased by the somewhat drastic alterations in the shape of the wings in the region of the ailerons. On the model the increase in drag coefficient was about 0.001, and on the full scale airplane was too small to be detected."

Translation by Dwight M. Miner,
National Advisory Committee for Aeronautics.

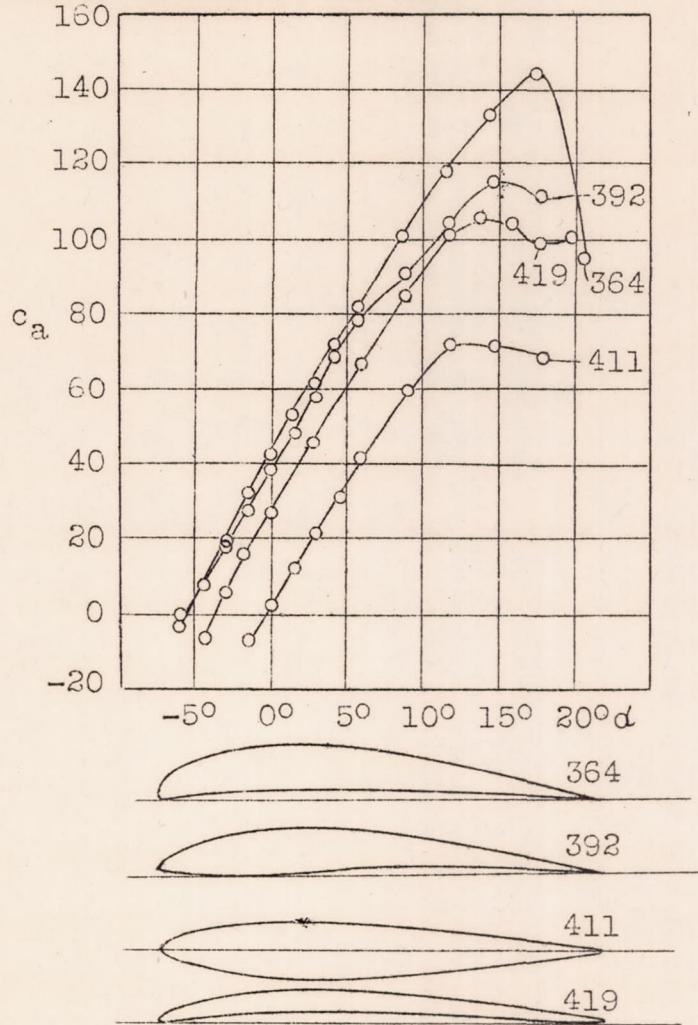


Fig.1

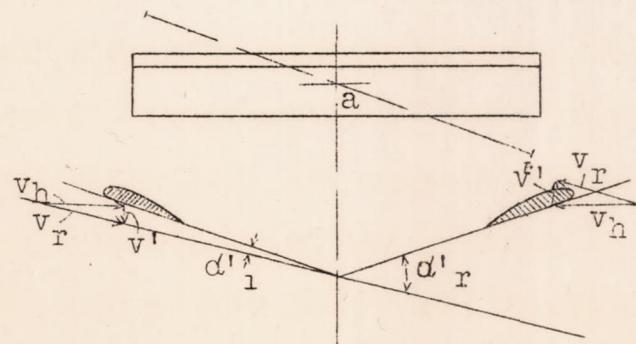


Fig.4

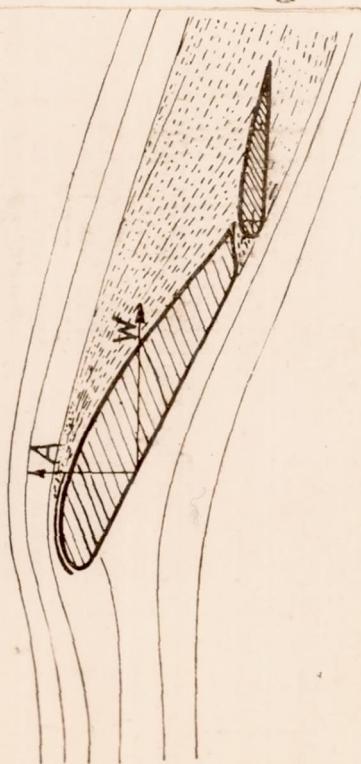
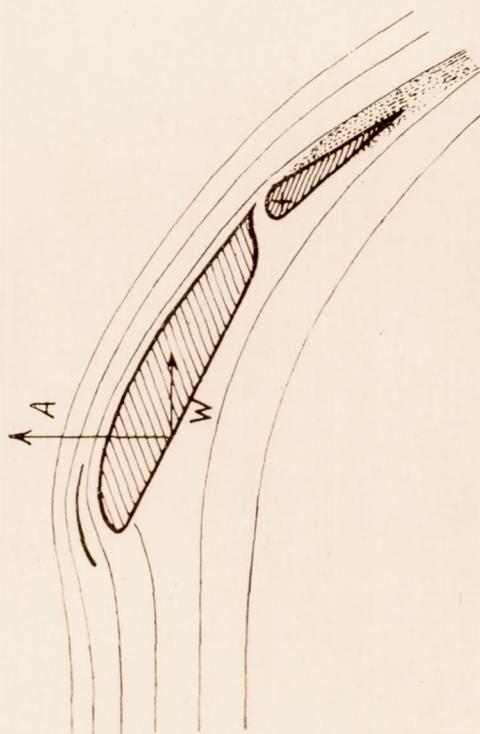


Fig.7



Fig.2



Fig.3

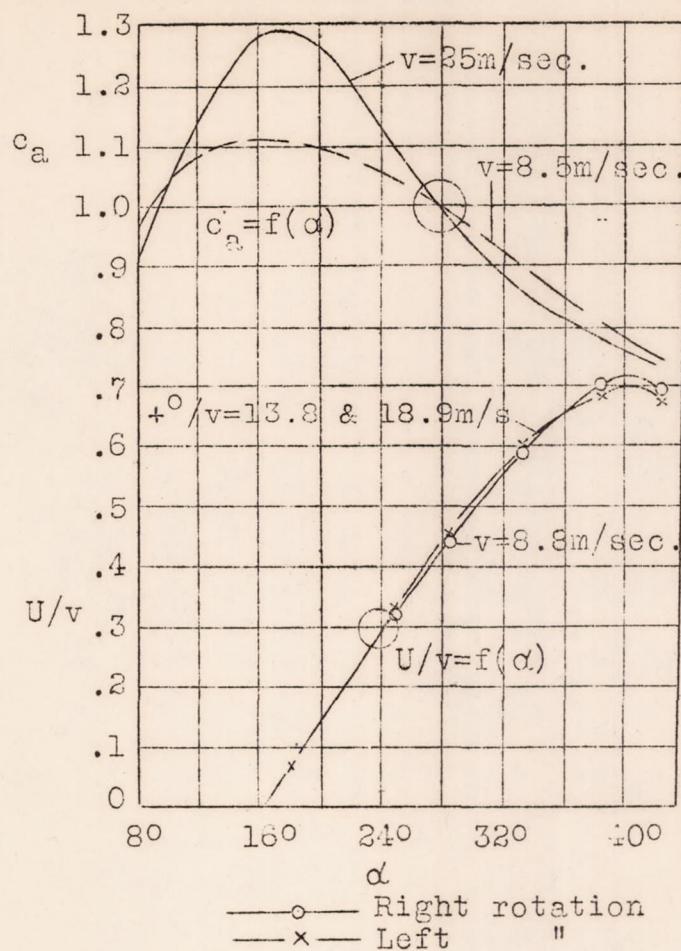


Fig.5

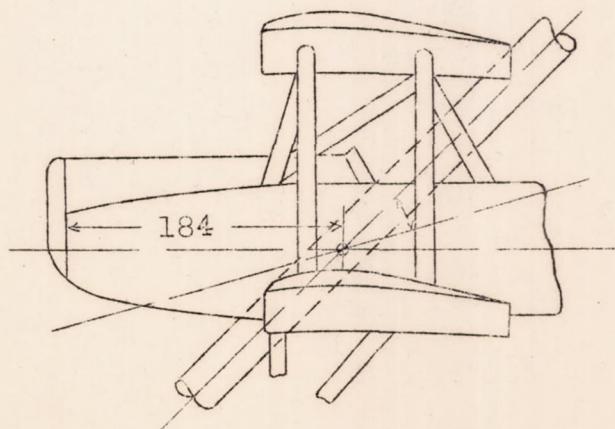


Fig.6

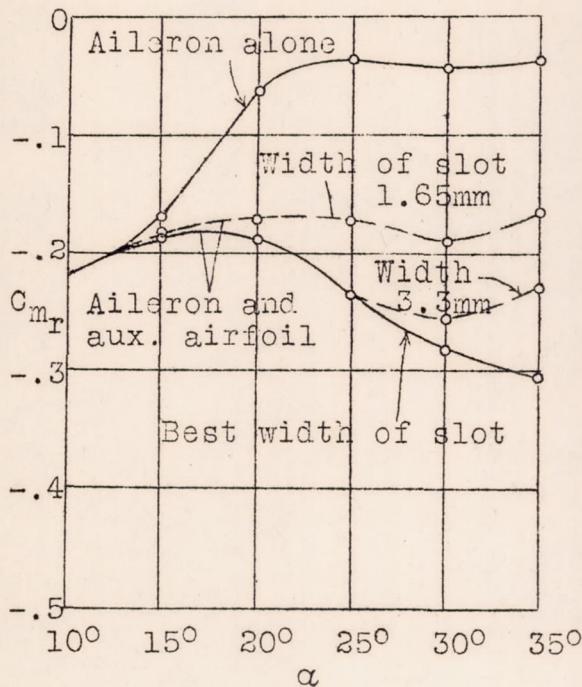


Fig. 8

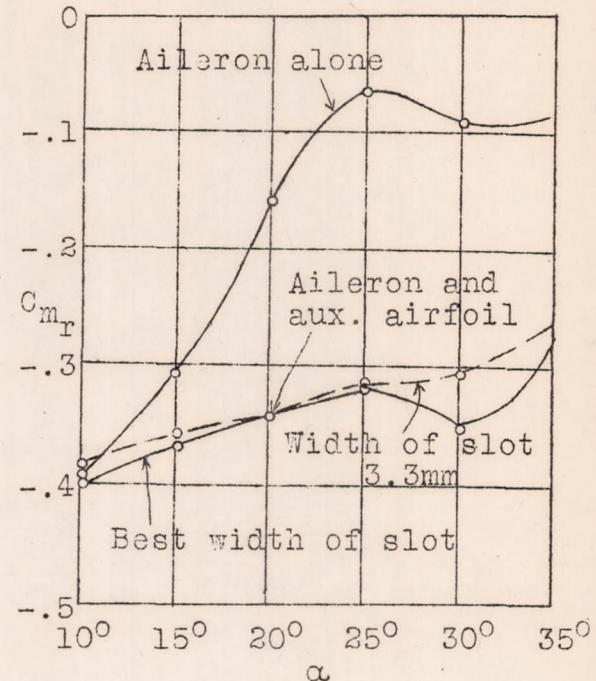


Fig. 9

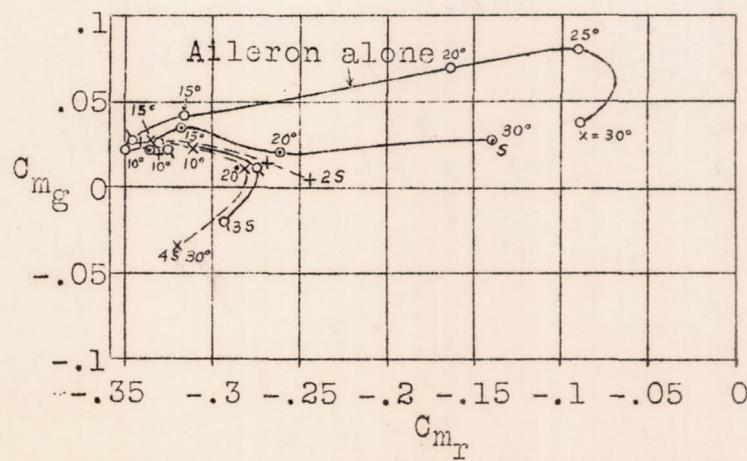


Fig. 10.